Journal of Cleaner Production 211 (2019) 1284–1298

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Biomass and carbon budgeting of land use types along elevation gradient in Central Himalayas

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ARTICLE INFO

Article history:
Received 13 December 2017
Received in revised form
29 August 2018
Accepted 28 November 2018
Available online 29 November 2018

Keywords:
Agroforestry
Biomass
Carbon budgeting
Elevation
Land use types
Himalayas

Abbreviations used:
AF
Agroforestry
BEF
Biomass expansion factor
BF
Banjoak forest
CF
Chirpine forest
C
Carbon
CO_2
Carbon di-oxide
GL
Grasslands
FSI
Forest survey of India
GSVD
Growing stock volume density
IPCC
Intergovernmental panel on climate change
MF
Mixed forest
VOB
Volume over bark

ABSTRACT

Biomass of vegetation is a crucial variable for understanding the potential future changes of the climate system. In the present study dominant land use types i.e. agroforestry (AF), banjoak forest (BF), chirpine forest (CF), mixed forest (MF) and grasslands (GL) of Himalayan region was investigated for biomass production and carbon stock budgeting in vegetation as well as in soil. Among land use type's highest aboveground biomass was recorded in banjoak forest (BF), 0.69%, 9.42% and 40.16% more than chirpine forest (CF), mixed forest (MF) and agroforestry (AF). However it was more than 16 times higher than grasslands (GL). Herbage and/or crops aboveground biomass was 3.73%, 4.05%, 4.42% and 29.34% of the aboveground biomass of trees in BF, CF, MF and AF. Herbage aboveground biomass was 76.01% of total aboveground biomass in grasslands. Our results revealed that in AF crops biomass accounted for 19.41 −26.60% and trees contributed 73.40−80.59% biomass in total biomass of land use. Likewise, similar contributions were recorded for belowground biomass and total biomass in land uses. Irrespective of land use types along elevation the total biomass including aboveground and belowground biomass significantly ($P < 0.01$) increased. Among land use types and along the elevation similar trend was recorded for vegetation carbon stock as it is the manifestation of biomass. Soil carbon density differed significantly in land use types with highest in BF and increased significantly along the elevation with highest at elevation E_5. Forest land uses stored 26.22% and 53.79% more total (vegetation + soil) carbon in than agroforestry and grasslands. The difference in carbon storage among land use types can be related to land use type, vegetation composition, their structural and functional characteristics viz., density, age and soil type. Thus, tree based land use types are more efficient for biomass production and carbon storage in changing climatic pattern.

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https://doi.org/10.1016/j.jclepro.2018.11.278
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WD
Volume weighted average wood density

1. Introduction

Globally livelihoods of ~40% people are being influenced by mountains. Indian Himalaya covers ~16.2% of India's total geographical area, and is divided into western, central and eastern Himalaya. It is mountainous characterizing by vertical zonation into elevational belts with gradual change in climate (Paudel and Vetaas, 2014), that contribute to alterations in biological diversity along elevation (Pook and Moore, 1966). Himalayan ecosystems are complex, with fragile environment, rugged terrain, unique topography and sensitivity to regional and global changes (Palni et al., 1998), therefore the region exhibits varied land use patterns and drastic changes in the landscape ecology in short distances.

The evidences suggest that Himalayan region is more sensitive to climate change (IPCC, 2007; Yadav et al., 2018) as parts of the Himalaya are warming at a significantly higher rate than the global average. This increased vulnerability has led to declined self-sufficiency that characterized the communities of this region is altered by increase in frequency of extreme climate events caused large losses of life and property (Thadani et al., 2015). Various studies indicate that climate change might influence forest vegetation includes changing phenological behaviour (Singh et al., 2015), upward shift of lowland species (Singh and Singh, 2013), change in nutrient dynamics (Thadani et al., 2015), invasion of alien species (Thadani et al., 2015), seed germination and regeneration (Singh and Singh, 2013) and frequency and intensity of occurrence of forest fires (Semwal et al., 2003) in Himalayan ecosystem.

India is among the world's ten most vulnerable countries to food crises and hunger induced by climate change, ranging from 20 to 40 per cent decline in agricultural productivity (IPCC, 2007). In Himalayan region subsistence agriculture is sustainable and changes in temperatures, erratic rainfall, frost events and glacier melt will influence hill agriculture in ways (Thadani et al., 2015). REDD+ is a scheme intended to compensate developing countries for protection and enhancement of forest carbon stocks can be used to support conservation, sustainable management and enhancement of the forests in Himalaya. Financial incentives would not only reduce pressure from the forests and mitigate the effects of climate change but also build community resilience by investing in modern technology (Thadani et al., 2015).

In the present altering climatic patterns biomass production and carbon storage are essential study areas in any land use which is a crucial variable for understanding the potential future changes of the climate system. Vegetation cover can have a direct influence on local, regional, and even global climate, particularly on air temperature and humidity, depending on the quantity of biomass (Yadav et al., 2015; Sadeghi and Raeini, 2016). Suitability of any plant community to the prevailing environmental conditions is determined by its estimated biomass. This biomass of vegetation is managed not only for environmental amelioration (Chang et al., 2017) and alternative source of energy (Esen and Yuksel, 2013) but also to improve socioeconomic condition of people. Woody biomass has great potential to provide a continuous and largely carbon-neutral raw material (Husmann et al., 2018).

Vegetation biomass analysis is also given priority because it is a major carbon sink. These woody perennial-based land use systems have relatively high capacities for capturing and storing atmospheric CO_2 in vegetation, soils, and biomass products (Yadav et al., 2017). Integrating carbon capture and storage into biomass can reduce carbon emissions (Pang et al., 2017). The biomass production depends upon a number of factors viz., growth habit of the species, site quality, soil on which trees are growing, stand age, management practices and their interactions with belowground components (Liu et al., 2015; Yadav et al., 2016a). Carbon footprints and land use can be reduced by eating less animal-based foods (Treu et al., 2017).

Hence, considering the impact of climate change on agrarian economy that entirely dependent on income or services from natural resources in Himalayan region. Information on biomass and carbon storage of land uses is inadequate thus the present investigation was undertaken to study land use with the following objectives: (i) measure vegetation biomass of different land use types, (ii) quantify carbon stock in vegetation biomass as well as in soil of land use types and (iii) vegetation biomass and carbon stock of land use types along elevation gradient and their interaction, if any.

2. Materials and methods

2.1. Study area

The present investigation was carried out in 2B4D6-watershed (The nomenclature given by Soil and Land Use Survey of India, New Delhi) in Almora district. This watershed is bounded between latitude 29°24′ to 29°52′ N and longitude 79°30′ to 79°51' E (Fig. 1) covering an approximately 78,483 ha area. The general terrain of this watershed is mountainous with altitudinal range from 800 m to above 2250 m above sea level (masl).

2.2. Vegetation

The vegetation distribution in 2B4D6-watershed is structured by altering micro-environment, especially temperature and moisture, along the altitude. Therefore, subtropical chir pine (*Pinus roxburghii*) thrives in the region between 800 and 1700 m and Himalayan moist temperate forests of Oak (*Quercus leucotrichophora*), Ayar (*Lyonia ovalifolia*), Kafal (*Myrica esculenta*) and Deodar (*Cedrus deodara*) are dispersed in altitudinal range from 1700 to 2200 m (Yadav et al., 2016c). In areas between 1000 and 1500 m, *Pinus* and *Quercus* forests overlap and form mixed forests (Negi et al., 2015).

The grasslands in lower Central Himalayan zone (1000–1800 m) are relatively xerophytic characterized by dominance of tropical plant genera like, *Apluda, Arundinella, Chrysopogon, Cymbopogon* and *Heteropogon*. In upper Central Himalayan zone (1800–3000 m) a mixture of tropical and temperate grasses is found with domination of temperate species like *Agropyron semicostatum*, *Phleum alpinum*, and *Dactylis glomerata*. The sub-tropical and temperate grasslands also have sporadic bushes.

In agroforestry systems rainy season crops (*Kharif*) were *Oryza sativa*, *Eleusine coracana*, *Glycine max*, *Zea mays*, *Vigna mungo* and winter season crops (*Rabi*) were wheat *Triticum aestivum*, *Brassica campestris*, *Lens esculenta*, and *Pisum sativum*. Among fruit trees *Citrus limon*, *Citrus sinensis*, *Juglans regia*, *Malus domestica*, *Pyrus communis*, *Prunus persica*, *Prunus armeniaca*, *Prunus domestica*, *Musa bauensis*, *Psidium gaujava*, *Punica granatum*. Forest trees in the area were *Celtis australis*, *Ficus palmata*, *Grewia optiva*, *Morus alba*, *Prunus cerasoides*, *Pyrus pashia*, *Alnus nepalensis*, *Bauhinia vareigata*, *Bauhinia retusa*, *Bombax ceiba*, *Ficus roxburghii*, *Grewia optiva*, *Melia azedarach*, *Quercus leucotrichphora* and *Toona ciliata* as reported by

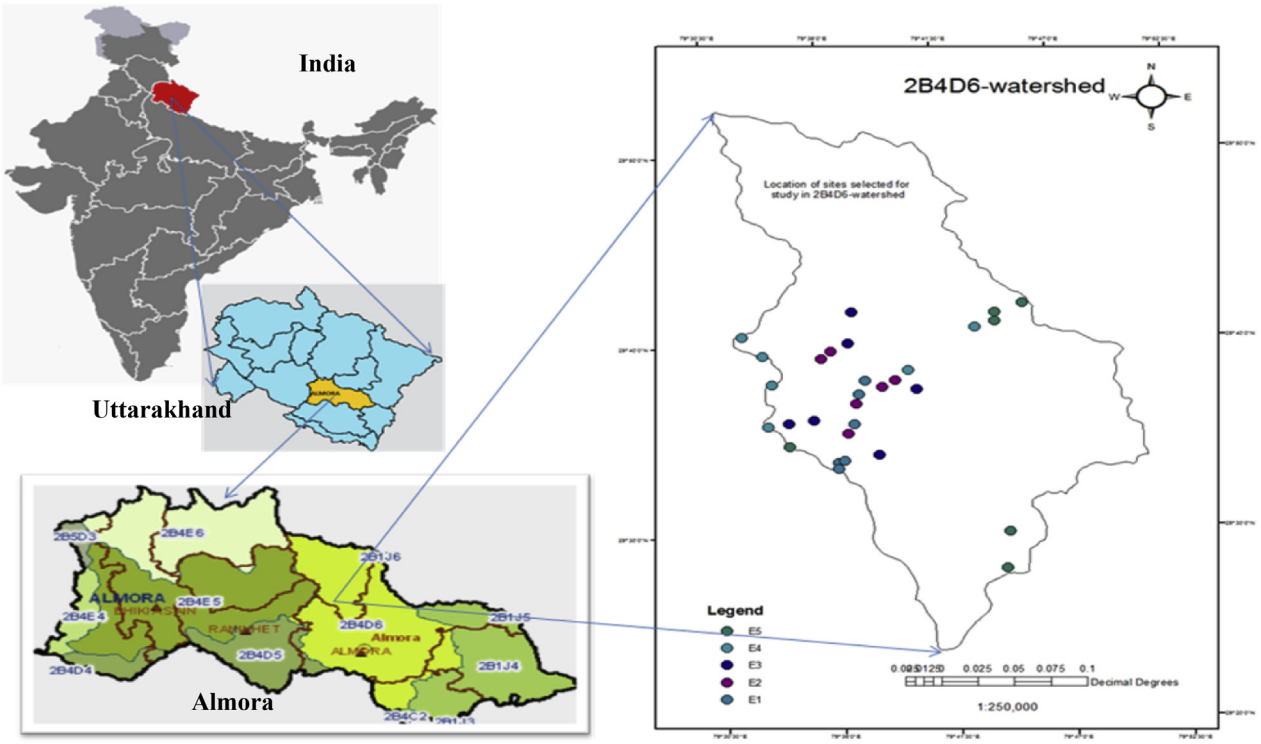

Fig. 1. Location of 2B4D6-watershed in Almora district of Uttarakhand.

Yadav et al. (2016c).

2.3. Climate

Climate in this watershed is sub-tropical in lower areas and wet-temperate in upper areas. Annual precipitation varies from 1000 mm in Hawalbagh to 2150 mm in Nainital. However, the mean annual precipitation in the area is around 1350 mm. The snow fall is a normal feature in areas above 1800 m. The meteorological record of the years 2001–2015 for Hawalbagh in Almora, a part of 2B4D6-watershed, revealed that mean annual maximum air temperature in this area varied between 25.64 and 26.79 °C, mean annual minimum air temperature fluctuated between 9.42 and 10.78 °C and mean annual air temperature hovered between 17.54 and 18.79 °C (Fig. 2). Annual rainfall in the area ranged from 667.90 mm to 1369.50 mm and the mean annual relative humidity fluctuated from 66.44% to 73.73%.

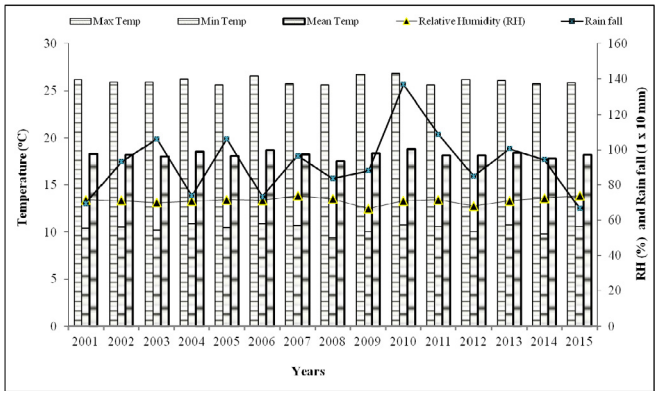
Max Temp
Min Temp
Mean Temp
Relative Humidity (RH)
Rain fall
Temperature (°C)
RH (%) and Rain fall (1 x 10 mm)
Years
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

Fig. 2. Meteorological record of 2B4D6-watershed in Central Himalaya.

2.4. Selection of experimental sites

The 2B4D6-watershed selected for the present study was stratified into five elevation zones as given below: $E_1 = < 1100$ m, $E_2 = 1101–1400$ m, $E_3 = 1401–1700$ m, $E_4 = 1701–2000$ m and $E_5 = > 2000$ m. In each elevation zone six representative experimental sites, each of around 1 km^2, were selected. The present study entailed land use types viz., agroforestry (AF), chirpine forest (CF), mixed forest (MF), banjoak forest (BF) and grasslands (GL).

2.5. Biomass estimations

2.5.1. Trees

In each land use type, 0.1 ha sample plot was laid out to study types and number of trees. The trees of different species in them were counted, averaged and density of each tree species was determined. Height of trees was measured by Ravi multimeter and dbh (diameter at breast height) was measured with tree caliper. Volume of tree species was calculated by using volume equations for specific tree species developed by FSI Dehradun for this region (FSI, 1996) or Forest Survey of India report (2009, 2011, 2012). Stem biomass of tree was obtained by multiplying volume with specific gravity (Smith, 1954).

$$\text{Stem biomass (t/ha)} = \text{VOB} \times \text{WD}$$

Where, VOB = volume over bark.WD = volume weighted average wood density.

The aboveground biomass of a tree was calculated following IPCC (2003) by multiplying its volume with a biomass expansion factor. The biomass expansion factor for hardwood, spruce-fir and

pine were calculated using the equations (Brown et al., 1999).

Aboveground biomass (t/ha) = Stem biomass (t/ha) × BEF

Where: BEF = biomass expansion factor.

Using the regression equation by Cairns et al. (1997), the belowground biomass (fine and coarse roots) was estimated for each tree. Above ground biomass and below ground biomass was added to derive at total biomass of trees.

2.6. Carbon stock estimation

Aboveground and belowground carbon content in plants was determined by multiplying biomass of trees, shrubs and herbs with a conversion factor of 0.45 (Magnussen and Reed, 2004; Woomer, 1999). Total carbon stock in vegetation was determined by adding above ground and below ground carbon. Composite soil samples (0–30 cm) from each sampling plot in different land use types were collected. They were air dried, crushed and passed through 2 mm sieve and stored in cloth bags. Soil organic carbon was estimated

Species	Equation	GSVD value
Hardwood	BEF = exp {1.91−0.34 × ln(GSVD)}	for GSVD ≤ 200 m^3 ha^{-1}
	BEF = 1.0	for GSVD > 200 m^3 ha^{-1}
Spruce-fir	BEF = exp {1.77−0.34 × ln(GSVD)}	for GSVD ≤160 m^3 ha^{-1}
	BEF = 1.0	for GSVD > 160 m^3 ha^{-1}
Pine	BEF = 1.68 Mg m−3	for GSVD < 10 m^3 ha^{-1}
	BEF = 0.95	for GSVD = 10–100 m^3 ha^{-1}
	BEF = 0.81	for GSVD > 100 m^3 ha^{-1}
Belowground biomass	BGBD = exp {−1.059 + 0.884 × ln(AGBD) + 0.284}	for all trees

2.5.2. Shrubs

Samples of stem, branch and leaf of each shrub species were collected. Belowground biomass of shrubs was determined by extracting roots from earth and washing them in running water. Fresh weight of each sample was taken and stored in separate paper bags. Fresh plant samples were kept in oven at 72 °C for 72 h or till the constant weight was obtained to determine their dry weight.

2.5.3. Herbs

The plants species harvested to get aboveground biomass, whereas belowground biomass of herbs was estimated by extracting a monolith of 25 × 25 × 25 cm from each quadrat. The soil was gently removed by tapping and plant species were segregated species wise, washed and dried in oven at 72 °C for 72 h till the constant weight was obtained.

2.5.4. Agriculture crop biomass

2-3 quadrats of size 2 m × 2 m were laid out in each agriculture field in kharif and rabi season crops. The sampling of different agriculture crops was done from these quadrats as follows:

(a) Vegetables (cabbage, cauliflower): Total number of plants (flower-heads) was counted in each quadrat and 2–5 plants of were sampled to determine aboveground and belowground biomass, yield, etc. In crops like colocasia, carrot, potato, radish the plants were uprooted from the quadrat to determine different parameters of biomass. In crops like pea capsicum, ochra, tomato, brinjal plants were harvested from sample plots and their aboveground biomass and yield was determined. Dry weight of different plants was determined by keeping the samples in oven at 72^{O}C for 72 h till the constant weight was achieved.

(b) Cereals and pulses: Cereals (wheat, maize etc) and pulses (soybean, lentil etc.) and oilseed crops (toria, mustard etc.) plants from each quadrat were harvested at ground level to determine aboveground biomass and yield. The belowground biomass of these crops was determined from their root shoot ratio.

Belowground biomass = aboveground biomass × Root: shoot ratio.

using the modified Walkley–Black method (Anderson and Ingram, 1993).

Bulk density (g/cm^3) = Oven dry soil weight (g) / Soil volume (cm^3)

The carbon stock in the soil was computed by using the formula given by Brown (2004) as follows:

Carbon stock (t/ha) = [Soil bulk density (g/cm^3) × soil depth (30 cm) × C] x 100

Where: C = carbon concentration in soil expressed as a decimal fraction.

2.7. Statistical analysis

Variation in biomass and carbon stock of vegetation as well as soil in different land use types and along the elevation was compared by using analysis of variance by using SPSS and JMP software.

3. Results

3.1. Biomass production

Comparing components biomass contribution (Table 1) in forest land uses it was recorded that contribution of trees in aboveground biomass varied between 77.31% (36.77 t ha^{-1}) in AF and 95.74% (63.81 t ha^{-1}) in BF. Whereas shrubs contribution ranged from 0.69% (0.46) in BF to 23.99% (0.89) in GL and herbs contributed from 3.57% (2.38) in BF to 76.01% (2.83) in GL. The trees contributed highest to belowground biomass of vegetation, and they accounted for 78.02% (13.21 t ha^{-1}) in AF to 92.57% (19.55 t ha^{-1}) in BF followed by herbage contribution that varied from 6.72% (1.42 t ha^{-1}) in BF to 86.76% (1.90 t ha^{-1}) in GL and the contribution of shrub species varied from 0.71% (0.15 t ha^{-1}) in BF to 13.24% (0.29 t ha^{-1}) in GL (Table 1). Trees, shrubs and herbs contribution in total biomass varied from 77.38% (49.81 t ha^{-1}) in AF to 94.01% (77.26 t ha^{-1}) in MF, 0.69% (0.61 t ha^{-1}) in BF to 20.00% (1.18 t ha^{-1}) in GL and 4.33% (3.80 t ha^{-1}) in BF to 80.00% (4.72 t ha^{-1}) in GL, respectively (Table 1).

Table 1
Composition of aboveground, belowground and total biomass (t ha^{-1}) production under different land use types in Himalayas.

Land use types	Components	Herbs/crops (H)	Shrubs (S)	Trees (T)	Total (H + S + T)
		Biomass (t ha^{-1})			
Agroforestry (AF)	Aboveground (AG)	10.79 ± 1.13 (22.69)	–	36.77 ± 9.06 (77.31)	47.56 ± 7.88
	Belowground (BG)	3.72 ± 0.63 (21.98)	–	13.21 ± 3.17 (78.02)	16.93 ± 2.70
	Total (AG + BG)	14.56 ± 1.44 (22.62)	–	49.81 ± 12.41 (77.38)	64.37 ± 10.48
Chirpine forest (CF)	Aboveground (AG)	2.56 ± 0.23 (3.87)	0.51 ± 0.06 (0.77)	63.12 ± 7.24 (95.36)	66.19 ± 6.99
	Belowground (BG)	1.71 ± 0.32 (8.81)	0.17 ± 0.03 (.88)	17.52 ± 1.92 (90.31)	19.40 ± 1.60
	Total (AG + BG)	4.27 ± 0.52 (4.99)	0.68 ± 0.08 (0.79)	80.64 ± 9.16 (94.22)	85.59 ± 8.58
Mixed forest (MF)	Aboveground (AG)	2.56 ± 0.23 (4.20)	0.49 ± 0.06 (0.80)	57.86 ± 7.33 (94.99)	60.91 ± 7.07
	Belowground (BG)	1.71 ± 0.32 (8.04)	0.16 ± 0.02 (0.75)	19.40 ± 1.94 (91.21)	21.27 ± 1.61
	Total (AG + BG)	4.27 ± 0.52 (5.20)	0.65 ± 0.08 (0.79)	77.26 ± 9.25 (94.01)	82.18 ± 8.67
Banjoak forest (BF)	Aboveground (AG)	2.38 ± 0.11 (3.57)	0.46 ± 0.02 (0.69)	63.81 ± 3.53 (95.74)	66.65 ± 3.50
	Belowground (BG)	1.42 ± 0.16 (6.72)	0.15 ± 0.01 (0.71)	19.55 ± 0.82 (92.57)	21.12 ± 0.70
	Total (AG + BG)	3.80 ± 0.13 (4.33)	0.61 ± 0.03 (0.69)	83.36 ± 4.34 (94.98)	87.77 ± 4.19
Grasslands (GL)	Aboveground (AG)	2.83 ± 0.36 (76.01)	0.89 ± 0.07 (23.99)	–	3.71 ± 0.41
	Belowground (BG)	1.90 ± 0.32 (86.76)	0.29 ± 0.02 (13.24)	–	2.19 ± 0.33
	Total (AG + BG)	4.72 ± 0.56 (80.00)	1.18 ± 0.08 (20.00)	–	5.90 ± 0.64

Note: - Values after ± sign is standard deviations.
- Values in parenthesis represents per cent of total in the respective rows.

Table 2
Aboveground, belowground and total biomass (t ha^{-1}) of vegetation in different land use types.

Land use types (LUT)	Aboveground biomass (t ha^{-1})	Belowground biomass (t ha^{-1})	Total biomass (t ha^{-1})
AF (n = 120)	47.55 **c**	16.88 **c**	64.50 **b**
CF (n = 30)	66.19 **a**	19.40 **b**	85.59 **a**
MF (n = 30)	60.91 **b**	21.27 **a**	82.18 **a**
BF (n = 12)	66.65 **a**	21.12 **a**	87.77 **a**
GL (n = 30)	3.71 **d**	2.19 **d**	5.90 **c**

Where, - AF = Agroforestry, CF = Chirpine forest, MF = Mixed forest, BF = Banjoak forest and GL = Grassland.
- Different successive letters suffixing the numbers in the columns denote significant difference at 0.01 level.

A perusal of Table 2 revealed that aboveground biomass of vegetation among land use types was significantly different (Adj $R^2 = 0.88$, F ratio = 405.19, $P < 0.0001$, t = 1.97) and it was maximum in BF (66.65 t ha^{-1}), which was at par in CF (66.19 t ha^{-1}), followed by in MF (60.91 t ha^{-1}), AF (47.55 t ha^{-1}) and minimum in GL (3.71 t ha^{-1}). The aboveground biomass of vegetation (herbs + shrubs + trees) in irrespective of land use types (Table 3) was highest at elevation E_5 (53.54 t ha^{-1}) and it decreased significantly (Adj $R^2 = 0.04$, F ratio = 3.61, $P < 0.007$, t = 1.97) with decrease in elevation in the order: E_4 (50.82 t ha^{-1}) > E_3 (46.08 t ha^{-1}) > E_2 (42.96 t ha^{-1}) > E_1 (40.04 t ha^{-1}). The interaction effect of land use types and elevations on aboveground biomass (Fig. 3) was significant (Adj $R^2 = 0.93$, F ratio = 2.82, $P < 0.001$, t = 1.97). The maximum aboveground biomass was recorded in CF at elevation E_5 (75.20 t ha^{-1}) and minimum in GL at elevation E_5 (3.32 t ha^{-1}).

Among different land use types belowground biomass (Table 2) was significantly high (Adj $R^2 = 0.87$, F ratio = 38.78, $P < 0.0001$, t = 1.97) in MF (21.27 t ha^{-1}) it decreased to 21.12 t ha^{-1} in BF which was at par to MF and it was lowest in GL (2.19 t ha^{-1}). An insight on change in belowground biomass along elevation irrespective of land use types (Table 3) showed that it was highest at elevation E_5 (17.71 t ha^{-1}) and decreased significantly (Adj $R^2 = 0.03$, F ratio = 2.49, $P < 0.04$, t = 1.97) along the elevation to 14.27 t ha^{-1} at elevation E_1. However, belowground biomass at elevation E_4 was at par with elevation E_3 and at E_3 with elevation E_2. The interaction effect of land use types and elevations on belowground biomass of vegetation (Fig. 4) showed that it did not vary significantly (Adj $R^2 = 0.90$, F ratio = 99.52, $P < 0.13$, t = 1.97), however highest belowground biomass of vegetation was recorded in MF at elevation E_5 (23.27 t ha^{-1}) and lowest in GL at elevation E_5 (1.74 t ha^{-1}).

The total biomass of vegetation in elevations irrespective of land use types (Table 3) revealed that it was highest at elevation E_5 (71.25 t ha^{-1}) and decreased significantly (Adj $R^2 = 0.04$, F ratio = 3.35, $P < 0.01$, t = 1.97) with decrease in elevation to lowest value of 54.37 t ha^{-1} at elevation E_1. Total biomass (Table 2) among land use types varied significantly (Adj $R^2 = 0.88$, F ratio = 406.03, $P < 0.0001$, t = 1.97) in the order: BF (87.77 t ha^{-1}) > CF (85.59 t ha^{-1}) > MF (82.18 t ha^{-1}) > AF (64.50 t ha^{-1}) > GL (5.90 t ha^{-1}). However, total biomass was statistically at par in BF, CF and MF. The interaction effect of land use types and elevations on total biomass (Fig. 5) was non-significant (Adj $R^2 = 0.92$, F

Table 3
Aboveground, belowground and total biomass (t ha^{-1}) of vegetation in land use types at different elevations.

Elevation (E)	Aboveground biomass (t ha^{-1})	Belowground biomass (t ha^{-1})	Total biomass (t ha^{-1})
E_1 (n = 42)	40.04 **c**	14.27 **c**	54.37 **c**
E_2 (n = 42)	42.96 **bc**	14.99 **bc**	57.96 **bc**
E_3 (n = 42)	46.08 **abc**	15.86 **abc**	61.95 **abc**
E_4 (n = 48)	50.82 **ab**	17.09 **ab**	67.99 **ab**
E_5 (n = 48)	53.54 **a**	17.71 **a**	71.25 **a**

Where, - E_1 = <1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m and E_5 = >2000 m.
- Different successive letters suffixing the numbers in the columns denote significant difference at 0.01 level.

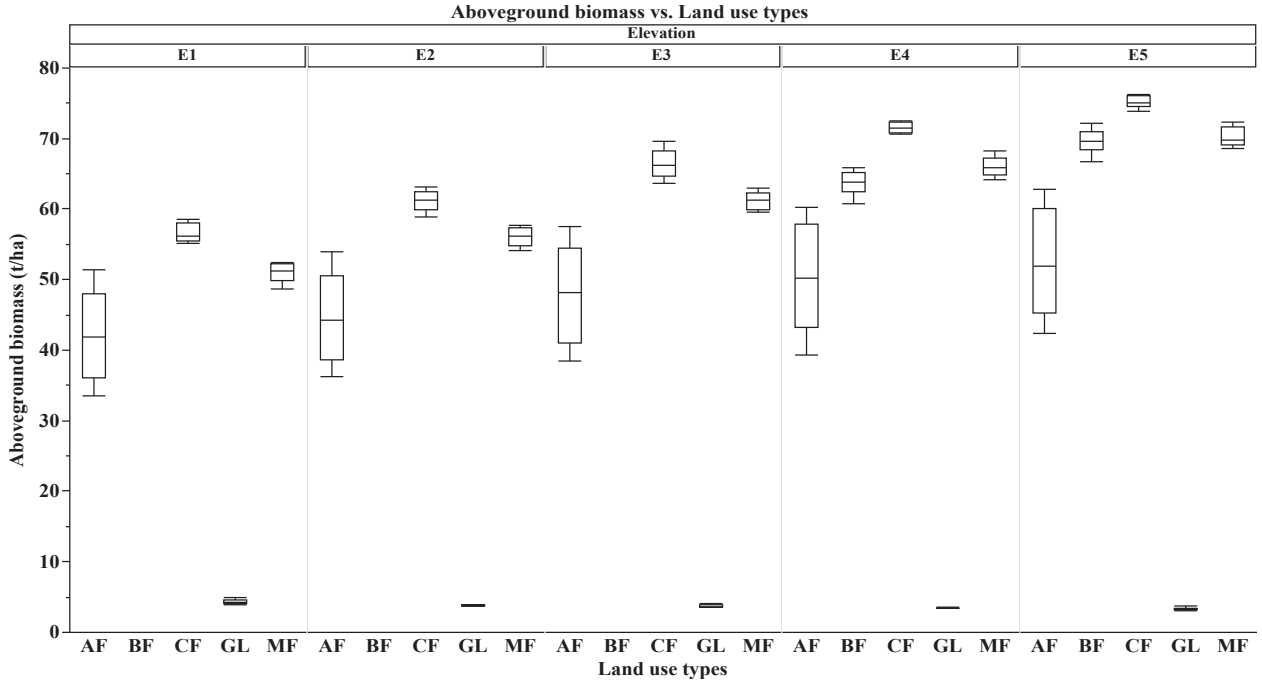

Fig. 3. Interaction effect of elevations and land use types on aboveground biomass of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

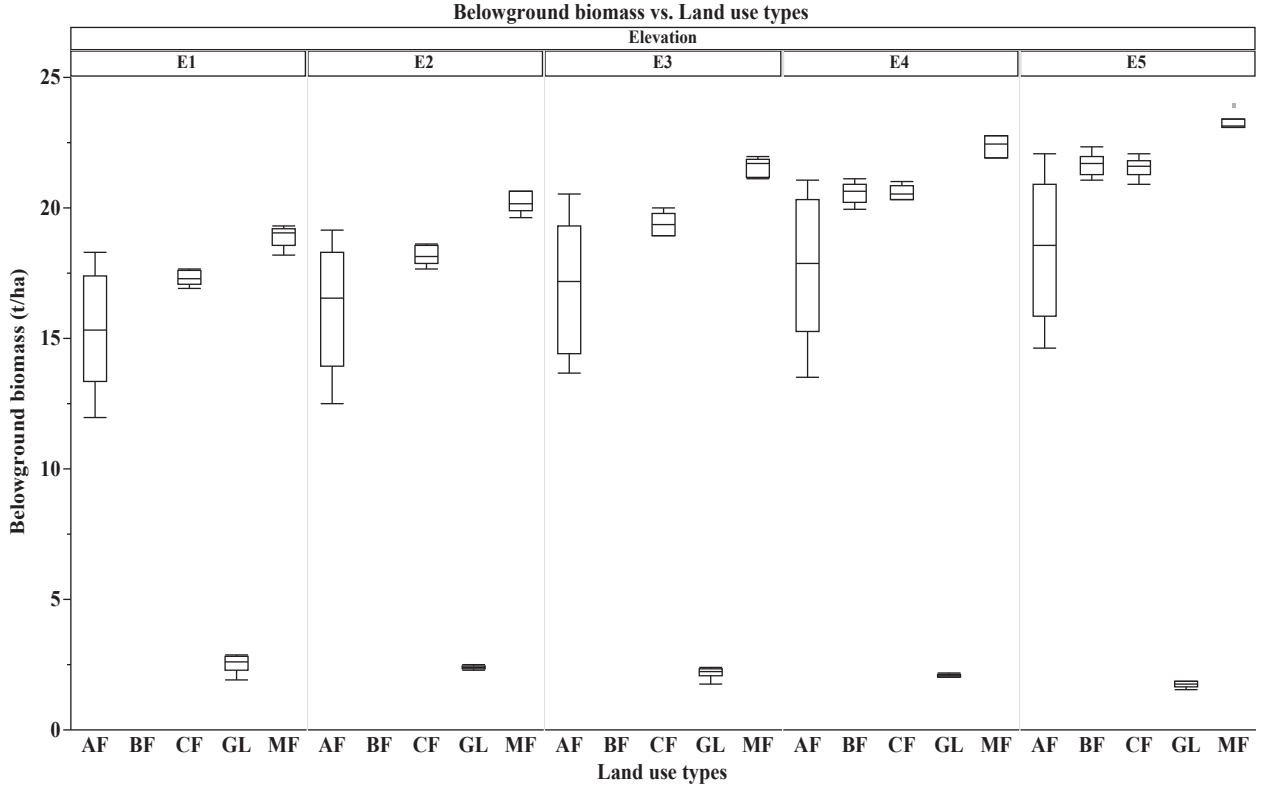

Fig. 4. Interaction effect of elevations and land use types on belowground biomass of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

ratio = 126.43, $P < 0.004$, $t = 1.97$). The maximum total biomass accumulated in CF at elevation E_5 (96.74 t ha^{-1}) and minimum in GL at elevation E_5 (5.07 t ha^{-1}).

3.2. Vegetation carbon stock

In land use types (Table 4), carbon storage in aboveground

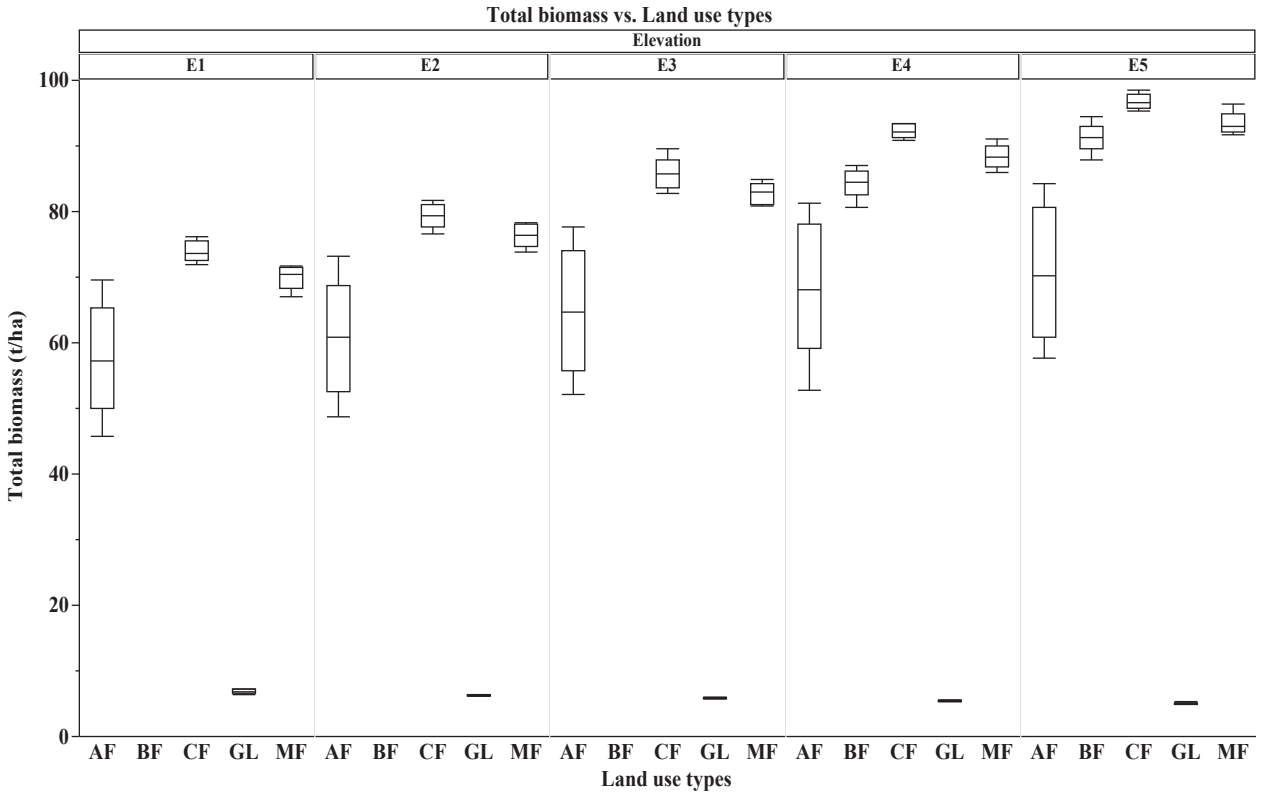

Fig. 5. Interaction effect of elevations and land use types on total biomass of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

Table 4
Composition of aboveground, belowground and total biomass carbon (t ha^{-1}) stock in different land use types.

Land use types (LUT)	Components	Herbs (H)	Shrubs (S)	Trees (T)	Total (H + S + T)
		Carbon density (t ha^{-1})			
Agroforestry (AF)	Aboveground (AG)	5.10 ± 0.50	–	16.42 ± 4.03	21.52 ± 3.63
	Belowground (BG)	1.75 ± 0.29	–	5.95 ± 1.42	7.69 ± 1.22
	Total (AG + BG)	6.84 ± 0.68	–	22.45 ± 5.40	29.28 ± 4.81
Chirpine forest (CF)	Aboveground (AG)	1.15 ± 0.10	0.23 ± 0.03	28.40 ± 3.26	29.78 ± 3.14
	Belowground (BG)	0.77 ± 0.14	0.08 ± 0.01	7.88 ± 0.87	8.73 ± 0.72
	Total (AG + BG)	1.92 ± 0.23	0.31 ± 0.03	36.29 ± 4.12	38.52 ± 3.86
Mixed forest (MF)	Aboveground (AG)	1.14 ± 0.10	0.22 ± 0.03	26.04 ± 3.30	27.41 ± 3.18
	Belowground (BG)	0.77 ± 0.14	0.07 ± 0.01	8.73 ± 0.87	9.57 ± 0.73
	Total (AG + BG)	1.92 ± 0.23	0.29 ± 0.03	34.77 ± 4.16	36.98 ± 3.90
Banjoak forest (BF)	Aboveground (AG)	1.07 ± 0.05	0.21 ± 0.01	28.71 ± 1.59	29.99 ± 1.57
	Belowground (BG)	0.64 ± 0.07	0.07 ± 0.005	8.80 ± 0.37	9.51 ± 0.32
	Total (AG + BG)	1.71 ± 0.06	0.28 ± 0.01	37.51 ± 1.95	39.50 ± 1.88
Grasslands (GL)	Aboveground (AG)	1.27 ± 0.16	0.40 ± 0.03	–	1.67 ± 0.18
	Belowground (BG)	0.85 ± 0.14	0.13 ± 0.01	–	0.98 ± 0.15
	Total (AG + BG)	2.13 ± 0.25	0.53 ± 0.04	-	2.65 ± 0.29

Note: - Values after ± sign is standard deviation.

biomass by different components varied from 16.42 t C ha^{-1} (AF) to 28.71 t C ha^{-1} (BF) by trees, 0.21 t C ha^{-1} (BF) to 0.40 t C ha^{-1} (GL) by shrubs and 1.07 t C ha^{-1} (BF) to 55.10 t C ha^{-1} (AF) by herbs and/or crops (Table 4). Belowground biomass carbon storage, in forest systems, varied between 5.95 t C ha^{-1} (AF) and 8.80 t C ha^{-1} (BF) by trees, 0.07 C ha^{-1} (MF, BF) and 0.13 C ha^{-1} (GL) by shrubs, 0.64 C ha^{-1} (BF) to 1.75 C ha^{-1} (AF) by herbs and/or crops. In land use types, total carbon storage by trees varied from 22.45 t C ha^{-1} (AF) to 37.51 (BF), whereas, shrub and herb species stored from 0.28 t C ha^{-1} (BF) to 0.53 t C ha^{-1} (GL) and 1.71 t C ha^{-1} (BF) to 6.84 t C ha^{-1} (AF), respectively (Table 4).

The data presented in (Table 5) revealed that among land use types aboveground biomass carbon was significantly (Adj $R^2 = 0.88$, F ratio = 392.56, $P < 0.0001$, t = 1.97) high (29.99 t C ha^{-1}) in BF, that was at par in CF (29.79 t C ha^{-1}) followed by in MF (27.41 t C ha^{-1}), in AF (21.54 t C ha^{-1}) and lowest in GL (1.67 t C ha^{-1}). The elevation showed significant (Table 6) effect on aboveground biomass carbon of vegetation and highest aboveground vegetation carbon (Adj $R^2 = 0.04$, F ratio = 3.54, $P < 0.008$, t = 1.97) was recorded at elevation E_5 (24.13 t C ha^{-1}) which decreased to 22.95 t C ha^{-1} at elevation E_4, 20.80 t C ha^{-1} at elevation E_3, 19.40 t C ha^{-1} at elevation E_2 and 18.14 t C ha^{-1} at elevation E_1. The interaction effect of land use types and elevations on aboveground biomass carbon (Fig. 6) was significant (Adj $R^2 = 0.9$, F ratio = 2.66, $P < 0.001$,

Table 5
Aboveground, belowground and total biomass carbon (t ha^{-1}) in different land use types.

Land use types	Aboveground biomass carbon (t ha^{-1})	Belowground biomass carbon (t ha^{-1})	Total biomass carbon (t ha^{-1})	Soil Carbon Density (t C ha^{-1})	Total Carbon Density (t C ha^{-1})
AF (n = 120)	21.54 **c**	7.67 **c**	29.21 **b**	57.30 **c**	86.51 **c**
CF (n = 30)	29.79 **a**	8.73 **b**	38.51 **a**	65.26 **b**	103.78 **b**
MF (n = 30)	27.41 **b**	9.57 **a**	36.98 **a**	66.48 **b**	103.46 **b**
BF (n = 12)	29.99 **a**	9.51 **a**	39.50 **a**	74.88 **a**	114.38 **a**
GL (n = 30)	1.67 **d**	0.98 **d**	2.65 **c**	65.88 **b**	68.54 **d**

Where, - AF = Agroforestry, CF = Chirpine forest, MF = Mixed forest, BF = Banjoak forest and GL = Grassland.
- Different successive letters suffixing the numbers in the columns denote significant difference at 0.05 level.

Table 6
Aboveground, belowground, total biomass carbon (t ha^{-1}) of vegetation, soil C density and total (vegetation + soil) C density of land use types at different elevations.

Elevation (E)	Aboveground biomass C (t ha^{-1})	Belowground biomass C (t ha^{-1})	Total biomass C (t ha^{-1})	Soil C density (t C ha^{-1})	Total C density (t C ha^{-1})
E_1 (n = 42)	18.14 **c**	6.46 **c**	24.61 **c**	51.29 **d**	75.90 **d**
E_2 (n = 42)	19.40 **bc**	6.79 **bc**	26.18 **bc**	56.13 **c**	82.32 **c**
E_3 (n = 42)	20.80 **abc**	7.18 **abc**	27.98 **abc**	63.42 **b**	91.41 **b**
E_4 (n = 48)	22.95 **ab**	7.73 **ab**	30.68 **ab**	66.83 **a**	97.52 **a**
E_5 (n = 48)	24.13 **a**	8.00 **a**	32.13 **a**	69.16 **a**	101.30 **a**

Where, - E_1 = <1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m and E_5 = >2000 m.
- Different successive letters suffixing the numbers in the columns denote significant difference at 0.05 level.

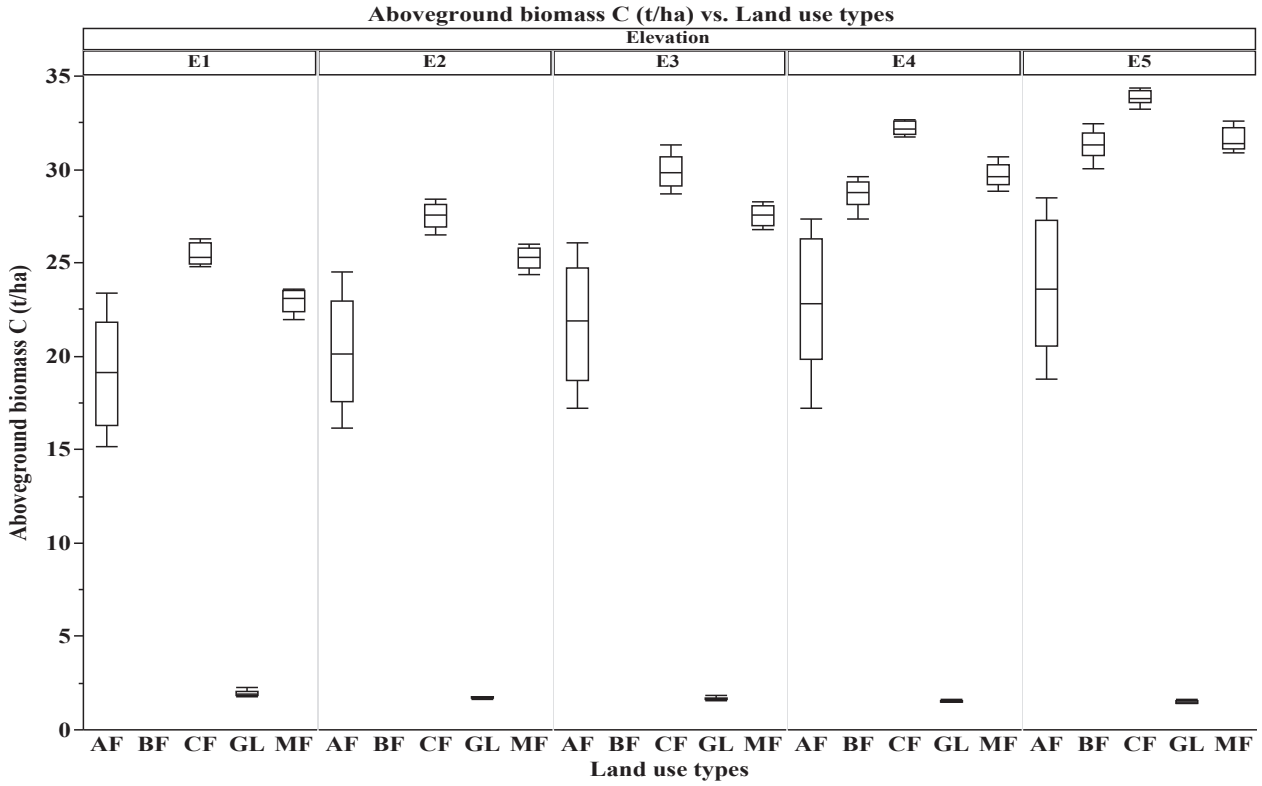

Fig. 6. Interaction effect of elevations and land use types on aboveground biomass C of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

t = 1.97). However, maximum aboveground biomass carbon was in CF at elevation E_5 (33.84 t C ha^{-1}) and minimum in GL at elevation E_5 (1.49 t C ha^{-1}).

The belowground biomass carbon (Table 5) in land use types was significantly (Adj R^2 = 0.88, F ratio = 388.05, P < 0.0001, t = 1.97) high as 9.57 t C ha^{-1} in MF, which was at par with 9.51 t C ha^{-1} in BF followed by CF (8.73 t C ha^{-1}), AF (7.67 t C ha^{-1}) and minimum belowground biomass carbon was recorded in GL (0.98 t C ha^{-1}). Irrespective of land use types belowground biomass carbon of vegetation (Table 6) increased significantly (Adj R^2 = 0.03, F ratio = 2.43, P < 0.04, t = 1.97) with increase in elevation, it was maximum (8.00 t C ha^{-1}) at elevation E_5 and decreased in the order: 7.73 t C ha^{-1} at elevation E_4 > 7.18 t C ha^{-1} at elevation E_3 > 6.79 t C ha^{-1} at elevation E_2 > 6.46 t C ha^{-1} at elevation E_1.

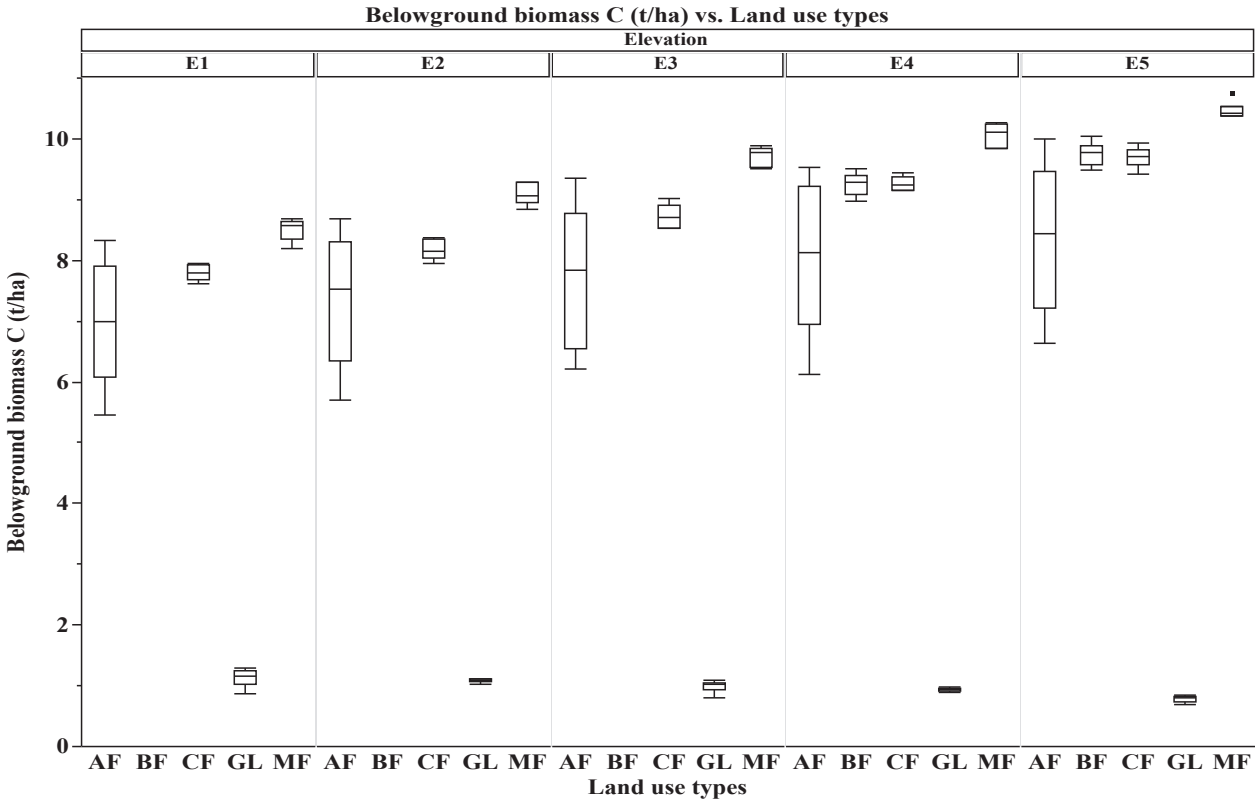

Fig. 7. Interaction effect of elevations and land use types on belowground biomass C of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

However, belowground biomass carbon at elevation E_3 was at par with elevation E_4 and at elevation E_2 with elevations E_3 and E_4. The interaction effect between land use types and elevations (Fig. 7) on belowground biomass carbon was non-significant (Adj $R^2 = 0.90$, F ratio = 1.44, $P < 0.14$, $t = 1.97$). However, highest belowground biomass carbon was recorded in MF at elevation E_5 (10.47 t C ha^{-1}) and it was lowest in GL at elevation E_5 (0.78 t C ha^{-1}).

The results (Table 5) exhibited that in different land use types, total biomass carbon significantly (Adj $R^2 = 0.88$, F ratio = 394.00, $P < 0.0001$, $t = 1.97$) high in BF (39.50 t C ha^{-1}) which decreased to 38.51 t C ha^{-1} in CF and lowest was in MF (36.98 t C ha^{-1}) but at par to each other followed by AF (29.21 t C ha^{-1}) and GL (2.65 t C ha^{-1}). A perusal of results (Table 6) revealed that total biomass carbon irrespective of land use types was significantly (Adj $R^2 = 0.04$, F ratio = 3.29, $P < 0.01$, $t = 1.97$) high as 32.13 t C ha^{-1} at elevation E_5 and decreased gradually along decreasing elevation to 24.61 t C ha^{-1} at elevation E_1. The interaction effect between land use types and elevations on total biomass carbon (Fig. 8) was significant (Adj $R^2 = 0.92$, F ratio = 2.31, $P < 0.007$, $t = 1.97$). However, maximum total biomass carbon was in CF at elevation E_5 (43.53 t ha^{-1}) and minimum in GL at elevation E_5 (2.27 t ha^{-1}).

3.3. Soil carbon density (t C ha^{-1})

Among land use types (Table 5) significant (Adj $R^2 = 0.32$, F ratio = 27.23, $P < 0.0001$, $t = 1.97$) maximum soil carbon density was recorded in BF (74.88 t C ha^{-1}) followed by MF (66.48 t C ha^{-1}), GL (65.88 t C ha^{-1}), CF (65.26 t C ha^{-1}), although soil carbon density in MF was at par with CF and lowest in AF (57.30 t C ha^{-1}). Soil carbon density irrespective of land use types increased significantly (Adj $R^2 = 0.54$, F ratio = 66.81, $P < 0.0001$, $t = 1.97$) along elevation (Table 6). Highest soil carbon density was recorded at elevation E_5 (69.16 t C ha^{-1}) and decreased in the order: E_4 (66.83 t C ha^{-1}) > E_3 (63.42 t C ha^{-1}) > E_2 (56.13 t C ha^{-1}) > E_1 (51.29 t C ha^{-1}). However, soil carbon density was at par at elevation E_2 with elevations E_1. The interaction effect between elevation and land use types (Fig. 9) on soil carbon density was significant (Adj $R^2 = 0.88$, F ratio = 12.64, $P < 0.0001$, $t = 1.97$). It was revealed that highest soil carbon density was at elevation E_4 in BF (75.22 t C ha^{-1}) and minimum at elevation E_1 in AF (44.61 C ha^{-1}).

3.4. Total (vegetation + soil) C density

It was also recorded that total carbon density (Table 5) was significantly (Adj $R^2 = 0.58$, F ratio = 77.72, $P < 0.0001$, $t = 1.97$) high in BF (114.38 t C ha^{-1}) and decreased in CF (103.78 t C ha^{-1}) that was at par in MF (103.46 t C ha^{-1}), further decreased in AF (86.51 t C ha^{-1}) and lowest in GL (68.54 t C ha^{-1}). Irrespective of land use types, perusal of data presented in Table 6 reveals that the total carbon density was significantly (Adj $R^2 = 0.33$, F ratio = 28.78, $P < 0.0001$, $t = 1.97$) high at elevation E_5 (101.30 t C ha^{-1}) which was at par with elevation E_4 (97.52 t C ha^{-1}) and it decreased significantly with decrease in elevation in the order: E_3 (91.41 t C ha^{-1}) > E_2 (82.32 t C ha^{-1}) > E_1 (75.90 t C ha^{-1}). The interaction effect of elevations and land use types on total carbon density (Fig. 10) was significant (Adj $R^2 = 0.87$, F ratio = 3.64, $P < 0.007$, $t = 1.97$). The maximum total carbon density (115.61 t C ha^{-1}) obtained in BF at elevation E_5, and minimum in AF (70.72 t C ha^{-1}) at elevation E_1.

4. Discussion

4.1. Biomass production

Among land use type's highest aboveground biomass was

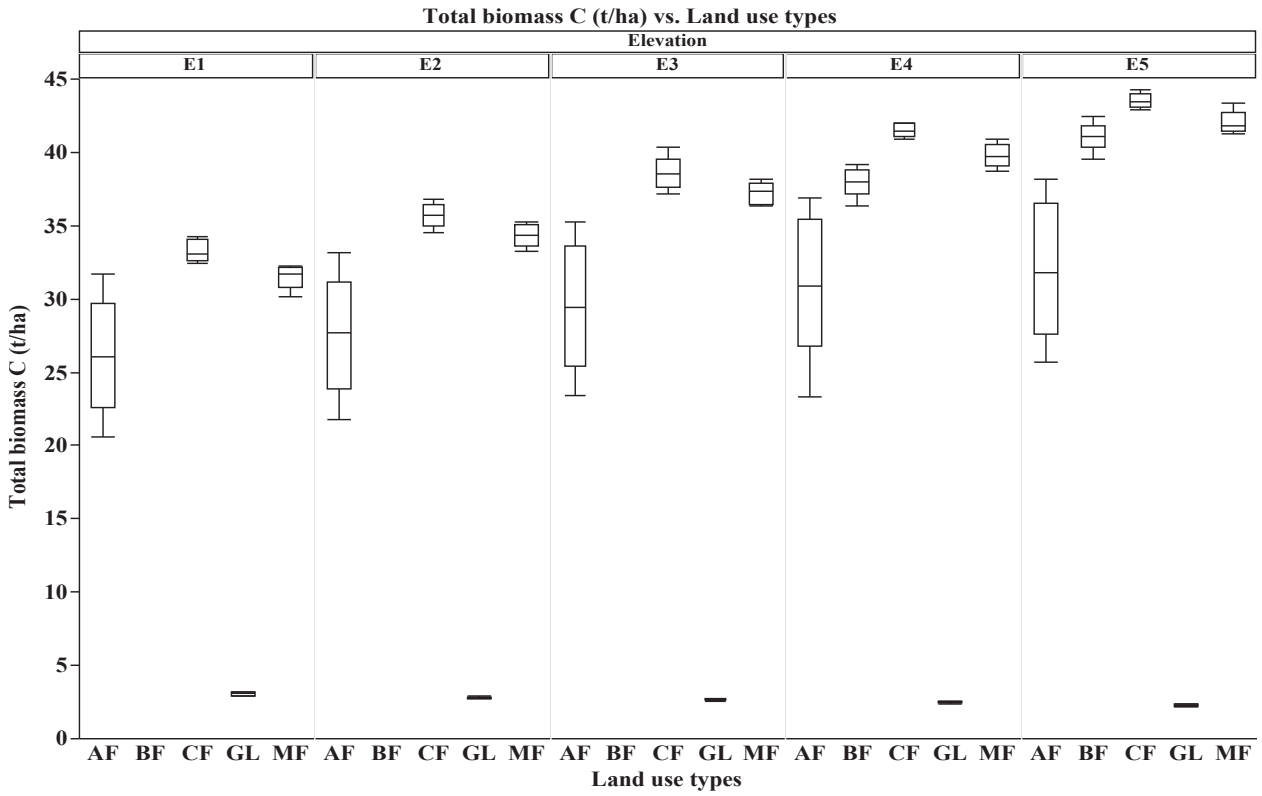

Fig. 8. Interaction effect of elevations and land use types on total biomass C of vegetation (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

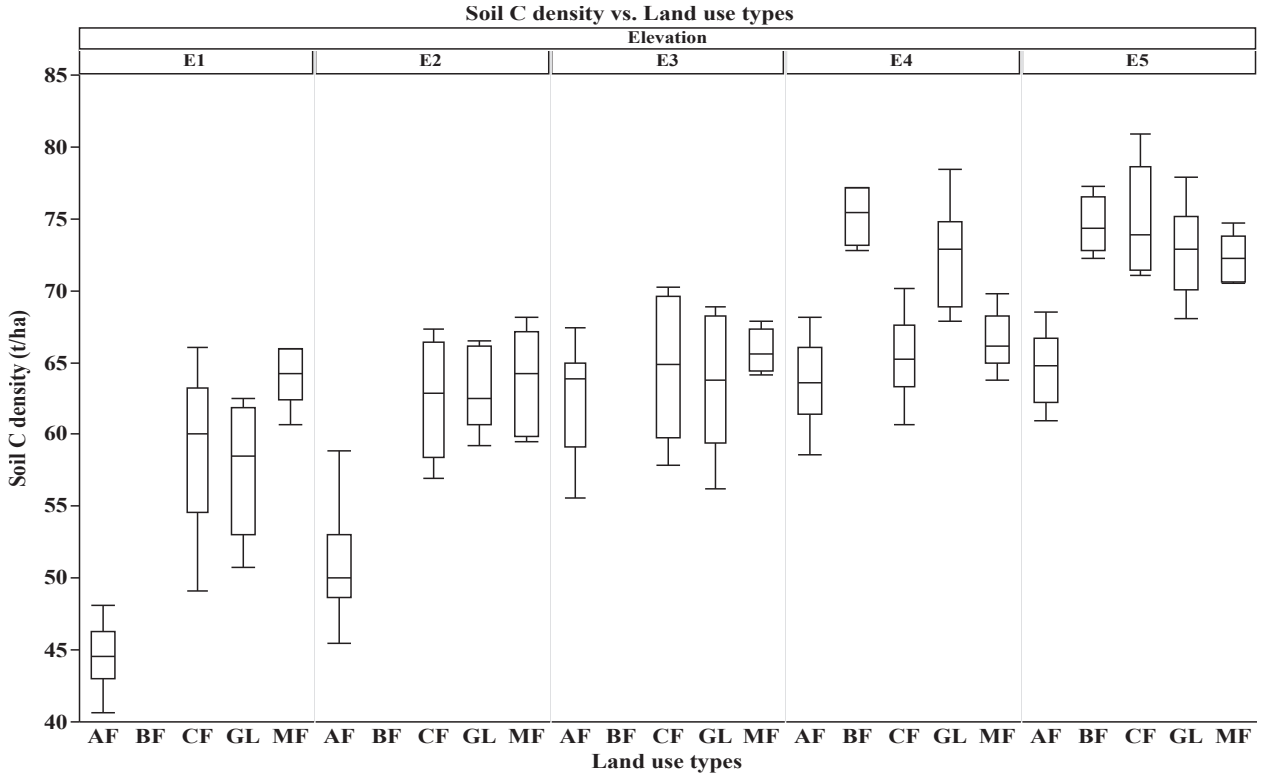

Fig. 9. Interaction effect of elevations and land use types on C density of soil (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; E_1 = < 1100 m, E_2 = 1101–1400 m, E_3 = 1401–1700 m, E_4 = 1701–2000 m, E_5 = > 2000 m).

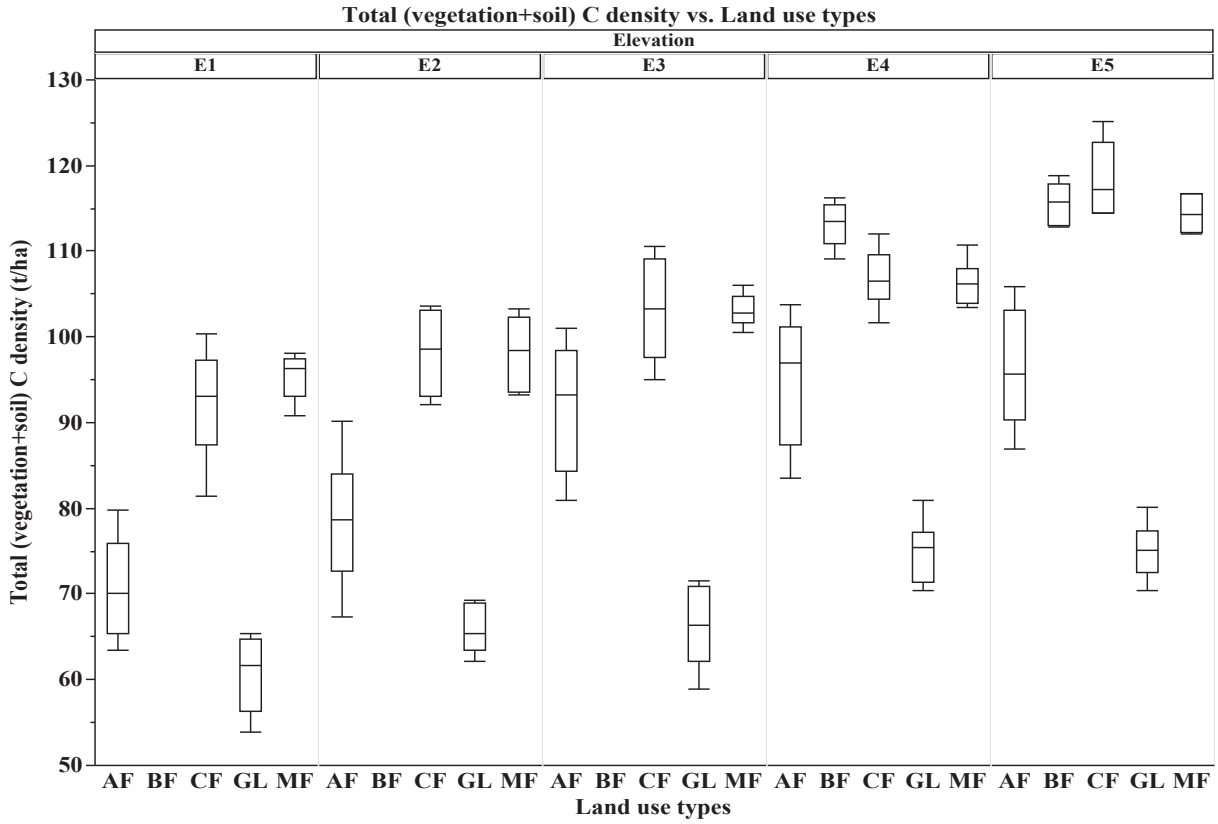

Fig. 10. Interaction effect of elevations and land use types on total (vegetation + soil) C density (AF = Agroforestry, BF = Banjoak forest, CF = Chirpine forest, MF = Mixed forest, GL = Grassland; $E_1 = < 1100$ m, $E_2 = 1101–1400$ m, $E_3 = 1401–1700$ m, $E_4 = 1701–2000$ m, $E_5 = > 2000$ m).

recorded in banjoak forest (BF), 0.69%, 9.42% and 40.16% more than chirpine forest (CF), mixed forest (MF) and agroforestry (AF). However it was more than 16 times higher than grasslands (GL). This can be attributed to *Q. leucotrichophora* trees which contributed 95.74% biomass to the total the total biomass of system (Table 1). This reveals that biomass in land use types largely depends upon species and abundance of woody plants as contended by Luedeling et al. (2011), Ensslin et al. (2015) and Yadav et al. (2017). Not only the type and number, individual tree size variation, which is generally quantified by variances in tree diameter at breast height (DBH) and height in isolation or conjunction, plays a central role in ecosystem functioning in both controlled and natural environments, including forests (Ali and Mattsson, 2017; Yadav et al., 2016a).

Herbage and/or crops aboveground biomass (Table 1) was 3.73% of the aboveground biomass of banjoak trees in BF, 4.05% of chirpine trees in CF and 4.42% of trees in mixed forest (MF) and 29.34% of trees in agroforestry (AF). Herbage aboveground biomass was 76.01% of total aboveground biomass in grasslands. Herbage and/or crops aboveground biomass in land use types recorded in the present study is in conformity to the findings of Mahato (2013) and Matber (2014) who reported that herbage and/or crops aboveground biomass accounted for 1.9–4.57% and 23.4–31.2% of the aboveground biomass of trees in forest and agroforestry, respectively and in grasslands ranging from 70.92 to 83.43% herbage biomass in Himalayas.

In the present study (Fig. 5) total biomass of vegetation was recorded as 60.96 to 70.87 t/ha in AF was, 71.91 to 93.82 t/ha in forest and 5.07 to 6.82 t/ha in grasslands at different elevations. Similar range of total biomass production in agroforestry, chirpine forests and grasslands in Himalayas has been reported by Goswami et al. (2014), Yadav et al. (2015, 2016a), Gupta et al. (2015).

Our results revealed that in AF crops biomass accounted for 19.41–26.60% and trees contributed 73.40–80.59% biomass in total biomass of the system. In forest systems herbage biomass contributed 4.33–5.21%, shrubs biomass accounted from 0.69 to 0.79% and trees contributed 94.01–94.98% biomass in the total biomass. While, in grasslands herbage biomass accounted for 80.00% and shrub biomass contributed 20.00% of the total biomass (Table 1). The results indicated that the biomass production in vegetation systems depended upon the species type, density, dominance and management beside species richness. The similar variations of biomass in agroforestry systems and grasslands have been reported by Soto-Pinto et al. (2010), Yadav et al. (2015) and Gupta and Sharma (2015). Soil condition and phenology (Gupta and Singh, 1981), better root networking, efficient and economical use of limited resources, higher photosynthetic activities, leaf area index, better light interception (Gupta and Sharma, 2015) and water use efficiency (Sehgal, 1999), are other reasons for difference in biomass production.

It was evident from Table 1 that herbage biomass production in forest systems (3.80–4.27 t/ha) was less than 5.90 t/ha in grasslands which is in conformity to the findings of various workers who have reported up to 34.00% decrease in aboveground biomass of herbage under chirpine trees as compared to grasslands (Matber, 2014; Gupta et al., 2015) in Himalayan region. The decrease in biomass under trees can be related to the reduction of light intensity under trees as reported by Heinrichs and Schmidt (2009). Decrease in LAI of herbage under trees has been held responsible for decrease in biomass of herbage by Gupta and Sharma (2015).

Total biomass of herbage recorded in the present study is similar to the findings of Gupta et al. (2015) who reported total biomass of

herbaceous vegetation ranging from 3.02 to 4.72 t/ha under different tree based systems and 7.64 t/ha in grasslands of Himalayas. According to Bahar (2003) climatic conditions, edaphic characteristics, phenology and floristic diversity regulate the production of any ecological system. In forest systems and grasslands at different elevations only few species contributed more to the biomass as compared to other plant species has also been reported by Gupta et al. (2015) for different vegetation.

Along the elevation the total biomass including aboveground and belowground biomass of AF and forest land use types significantly increased while it significantly decreased in grasslands (Figs. 3–5). The increase in the biomass of agroforestry systems was mainly due to difference in tree (species & number) components. The mean aboveground, belowground and total biomass was higher in forest land uses (BF, MF & CF) as compared to agroforestry (AF) and it was least in grasslands (GL) both along the elevation and among the systems. In Himalayas the same results in similar agroforestry have also been reported by many researchers (Yadav et al., 2015, 2016a; Rajput et al., 2016) and in forests (Dimri et al., 2014; Goswami et al., 2014).

The increase in the biomass along the elevation in agroforestry and forests land uses suggests that precipitation is the main determinant of biomass variation in Himalaya as precipitation increases upto 2400 m elevation (Kansakar et al., 2004; Shrestha et al., 2012), with maximum rainfall between 2000 and 2400 m amsl (Dhar and Bhattacharya, 1976). Increase in total biomass, aboveground biomass and belowground biomass of vegetation in agroforestry and forest systems increased along elevation have been reported by Sharma (2009) and Matber (2014) in Himalayas. Whereas, Ensslin et al. (2015) reported an increase in biomass with elevation up to 2500 m which was below tropical tree line. Other studies in mountains also reported increase of biomass with elevation (Culmsee et al., 2010; Marshall et al., 2012). Elevated level of soil organic carbon at higher elevation might have favoured biomass production as contended by Rao et al. (1988) and Lehmann et al. (1998).

In grasslands, aboveground, belowground and total biomass herbaceous vegetation decreased significantly along the elevation with a mean value of total biomass as 5.90 t/ha. Many workers have contended that this decline is due to change in environment conditions along the altitude (Perez and Frangi, 2000; Sevgi and Tecimen, 2008). Similar variations in biomass along the elevation in grasslands in Indian Himalaya have also been reported by Mahato (2013) and Matber (2014) and, elsewhere in the world by Perez and Frangi (2000). Higher herbage biomass production i.e. 6.7 and 7.4 Mg ha^{1} have been reported in the South American Andes, Paramo and Puna vegetation by Gibbon et al. (2010) and Oliveras et al. (2014).

4.2. Vegetation C stock

The carbon sequestration potential of land use types has been endorsed by IPCC third assessment report on climate change to increase carbon stock in farm lands and mitigate greenhouse gas problems through economic, environmental and socioeconomic benefits (Rizvi et al., 2011), with a technical mitigation potential of 1.1–2.2 Pg C in terrestrial ecosystems over the next 50 years (Kumar and Nair, 2011). In land uses C sequestration primarily involves the uptake of atmospheric CO_2 during photosynthesis and the transfer of fixed C into vegetation, detritus, and soil pools for long-term storage in aboveground and belowground major segments (Nair et al., 2010). Carbon storage in vegetation ecosystems plays vital role in the global carbon cycle (Li et al., 2013; Zhao et al., 2014).

The difference in biomass carbon in land use types can be related to the biomass and, thereby the biomass carbon, of aboveground components depends upon a number of factors like, number and growth habit of the species, site quality, soil on which trees are growing, stand age, management practices and their interactions with belowground components (Weifeng, 2011; Kumar et al., 2012; Yadav et al., 2016a). Thus, the carbon storage in land uses is regulated by type of species and their number in them, which confirms that to capture and store atmospheric CO_2 in vegetation, woody perennials have relatively high capacities.

In land use types (Table 5), the aboveground biomass carbon decreased in the order: BF (29.99 t C ha^{-1}) > CF (29.79 t C ha^{-1}) > MF (27.41 t C ha^{-1}) > AF (21.54 t C ha^{-1}) > GL (1.67 t C ha^{-1}). In banjoak forest, trees stored 95.73% carbon in aboveground biomass followed by chirpine forest in which 95.37%, in mixed forest 95.04% and in agroforestry 76.30% of the carbon was stored in aboveground biomass (Table 4). The contribution of shrubs and herbs was less than 6.00% in aboveground biomass carbon in all land use types. The belowground biomass carbon density of vegetation was highest in MF (9.57 t C ha $^{-1}$) followed by BF (9.51 t C ha $^{-1}$), CF (8.73 t C ha $^{-1}$), AF (7.67 t C ha $^{-1}$) and GL (0.98 t C ha $^{-1}$) while total biomass carbon density of vegetation in land use types followed the similar trend as aboveground biomass carbon (Table 5). Similar findings on carbon stock of different components of vegetation in forests have been reported by Goswami et al. (2014), Gupta et al. (2015) and Rajput et al. (2016) in Himalayas.

Trees contribution in belowground biomass carbon was 92.53% in BF, 91.22% in MF, 90.26% in CF and 77.37% in AF. Whereas, in total biomass carbon trees stored 94.96%, 94.21%, 94.02% and 76.67% carbon in BF, CF, MF and AF, respectively (Table 4). Both, herbs and/or crops and shrubs, together, contributed less than 24.00% and 6.00% carbon to belowground and total biomass carbon of vegetation in forest systems. Palm et al. (2004) and Haile et al. (2008) contended that net aboveground as well as belowground carbon sequestration increases due to incorporation of trees on crop and pasture lands.

In aboveground, belowground and total biomass of grasslands 76.05%, 86.73% and 80.38% of carbon was locked in herbage and rest was contributed by shrubs (Table 4). Enough reports are available in literature that explains the structural components and their management in agroforestry systems which regulates their carbon sequestration potential (Goswami et al., 2014; Yadav et al., 2015, 2016a; Rajput et al., 2016). Beside these factors, differences in productivity and carbon sequestration potential of land use types also occur due to the decision making process for selecting land uses and management practices influenced by socioeconomic factors (Seabrook et al., 2008; Yadav et al., 2016c) and prevailing ecological variations (Rizvi et al., 2011; Yadav et al., 2016a). In similar ecological conditions tree based systems stores more carbon than grasslands or grown field crops (Roshetko et al., 2002; Kirby and Potvin, 2007).

Along the elevation total biomass carbon including aboveground and belowground biomass carbon of agroforestry and forests increased significantly while it decreased significantly in grasslands. The increase in biomass carbon of agroforestry can be related to number of tree components in agroforestry systems (Table 4). Similar trend in carbon storage along the elevation in Himalayas have also been reported by many researchers in similar type of agroforestry (Goswami et al., 2014; Yadav et al., 2016a, 2017), in forests (Dimri et al., 2014; Rajput et al., 2016). In grasslands reverse trend of vegetation biomass carbon along the elevation can be related to the decrease in biomass along the elevation. Such trend in biomass variation in grassland is due to change in environment conditions along the altitude (Perez and Frangi, 2000; Jamwal and Uniyal, 2008).

4.3. Soil carbon density

Soil carbon storage in forest systems is more (65.26–74.88 t/ha) as compared to in soil of AF (57.30 t/ha), this variation is due to difference in structural components with respect to space and time. Similar observations also recorded by many researchers (Zhang et al., 2011; Kell, 2012; Gupta et al., 2015) that structural components and their management effect soil carbon storage. Beside this, type of soil (Gupta et al., 2009; Chiti et al., 2012) and age of the plantations (Chauhan et al., 2015) are the factors which regulate soil carbon storage in land use types. This enhanced soil organic carbon density can be retained for millennia (Schmidt et al., 2011; Mbow et al., 2014) and may amount up to 300 Mg C ha^{-1} in 1 m depth of soil (Lorenz and Lal, 2014).

The soil carbon density among forest land use especially in BF 74.88 t C ha^{-1} was considerably higher than grasslands (65.88 t C ha^{-1}) understandably due to addition of organic carbon via litter fall and its decomposition that is absence in grasslands may be because of regular livestock grazing. The highest carbon stock in banjoak forest soils was due to higher percent of soil organic carbon in this forest through higher litter input which results in maximum storage of carbon stock as compared to others systems. Similar finding was reported by Sheikh et al. (2009) in forests of Garhwal Hiamalaya. Growing trees flourish rooting system (Blevines and Frye, 1993) and litter addition (Yadav and Bisht, 2014) perhaps that also increase soil carbon storage which was confirmed by Singh (2005) with positive correlation between soil organic carbon and quantity of litter fall. Woodall and Liknes (2008) suggested that coarse and fine woody debris contribute to soil carbon stock of forest ecosystem, which was more common in banj oak forest as the species is lopped to get fodder. Jha et al. (2001) reported that carbon stored in Indian soils range from 13.2 to 120.4 t C ha^{-1}, our finding is well within this range.

In the present investigation it was evident that soil organic carbon storage was influenced by vegetation type. Many workers endorse this view and have recorded a range of 26.37–219.86 Mg C ha^{-1} in soils of agroforestry/forests/grasslands in Himalayas (Devi et al., 2013; Gupta et al., 2015; Rajput et al., 2016; Mahato et al., 2016). In other parts of the world, a range of 35.8–92.6 Mg C ha^{-1} in soils have been reported by Usuga et al. (2010).

It was recorded that in different systems soil carbon density increased along the elevation (Fig. 9). Other workers have also recorded similar increase in soil carbon density such as Tashi et al. (2016) in the forests of eastern Himalaya; Bolstad and Vose (2001), Garten (2004), Tsai et al. (2013) and Shelukindo et al. (2014) in other parts of the world, in their studies they reported that soil carbon stock increased with altitude in mountainous terrain. This increase in soil organic carbon density is due to slow decomposition of organic matter at higher elevation that results in organic matter accumulation. Similar findings were reported by many researcher such as Tang et al. (2012), Hoffmann et al. (2014) and Negash and Starr (2015) who contended that the higher elevation conditions favour relatively accumulation of more soil carbon stock compared to the lower elevation.

4.4. Total (vegetation + soil) carbon density

In AF total carbon storage was in the tune of 86.51 t C ha^{-1}, in forests it was 103.46–114.38 t C ha^{-1} and in grasslands 68.54 t C ha^{-1} (Table 5). Thus, forest land uses stored more carbon than AF and grasslands. They stored 26.22% and 53.79% more carbon than AF and grasslands. The difference in carbon storage among land use types can be related to land use type, vegetation composition, their structural and functional characteristics viz., density, age, photosynthetic efficiency etc., soil and climate as debated by Oelbermann et al. (2006), Goswami et al. (2014), and Yadav et al. (2016b). Similar range of carbon storage in agroforestry, forests and grasslands have also been reported by Goswami et al. (2014), Gupta et al. (2015) and Rajput et al. (2016) in Himalayas.

Similar range of total carbon stock was also reported in other parts of India ranging from 31.20 to 173.90 t C ha^{-1} (Chauhan et al., 2015) and in world by Krankina and Dixon (1994) for agroforestry of humid tropical regions of southeast Asia (12–228 Mg C ha^{-1}). But, present estimates are far above the range recorded by Winjum et al. (1992) for agroforestry of low humid tropical regions of northern Asia (15–18 Mg C ha^{-1}) and by Manhas et al. (2006) in conifers of temperate region in India between 28.88 and 65.21 t/ha which are well below than the present estimates.

The total carbon density in systems increased along elevation as like soil carbon density and biomass carbon density. The reasons for such result are the same as explained earlier for soil carbon stock i.e., more accumulation of soil carbon due to slow decomposition and deposition of high organic matter (Garten et al., 1999; Tsai et al., 2013; Tashi et al., 2016) and increasing biomass carbon density along elevation due to variation in structural composition of vegetation (Lehmann et al., 1998; Shrestha et al., 2012; Ensslin et al., 2015).

5. Conclusions

In the present study biomass production and carbon stock of vegetation differed with land use types. They were considerably higher in tree based land use types as compared to grasslands and followed the order: BF > CF > MF > AF > GL. As trees produce more biomass and subsequently they store more carbon. Likewise, biomass and carbon stock increased along increasing elevations and followed the trend: $E_1 < E_2 < E_3 < E_4 < E_5$. With increasing elevation there was lesser disturbance to land uses at higher elevations in comparison to lower elevation due to this they produced more biomass. Soil carbon density was also higher in banjaok forest as compared to other land uses due to addition of more litter to the soil, which increased the soil organic carbon of the soil. Along the elevation slower decomposition of the organic matter was responsible for increased soil carbon density. Similarly, total (vegetation + soil) carbon density was also followed same trend as the biomass and carbon stock of the vegetation. So, it is confirm from this study that tree based land uses are more suitable for biomass and carbon storage in this changing climatic scenario.

Acknowledgements

The authors are grateful to the Director of Reasearch, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan-173230, Himachal Pradesh for providing necessary support.

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